The LUX-ZEPLIN Dark Matter Search

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for the LZ collaboration

DBD18

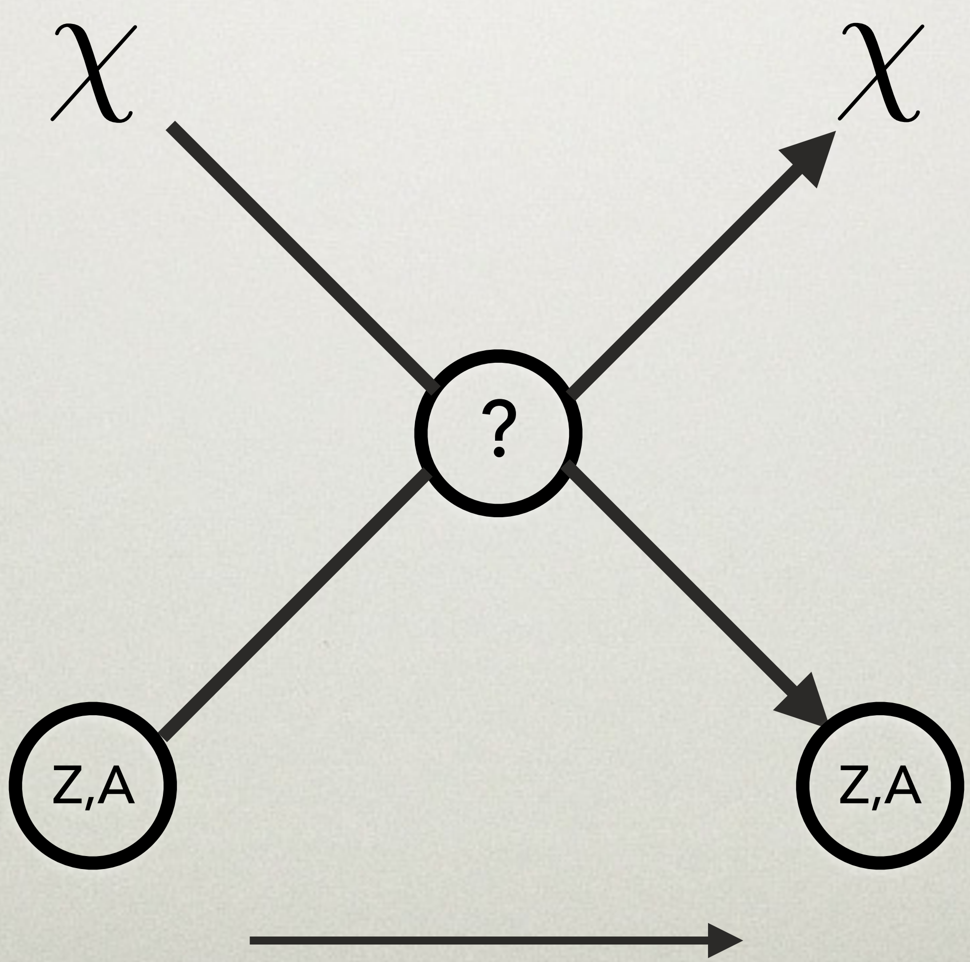
International Workshop on Double Beta Decay and Underground Science

Hilton Waikoloa Village, Hawaii, USA

21-23 October, 2018

LUX-ZEPLIN

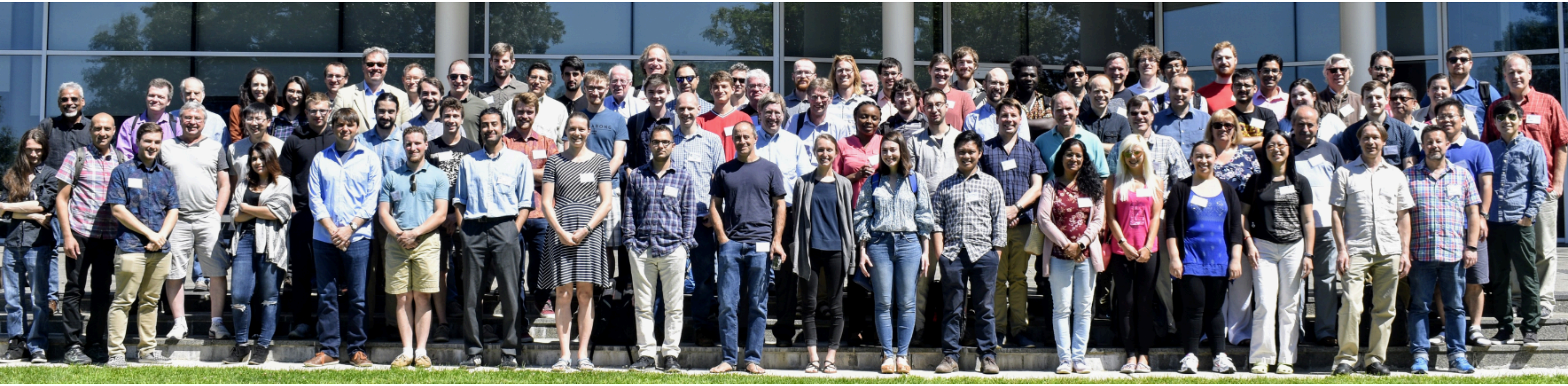
A direct-detection search, looking primarily (but not only) for WIMP dark matter with a xenon nucleus



LZ collaboration, June 2018

36 institutions

250 scientists, engineers, and technicians

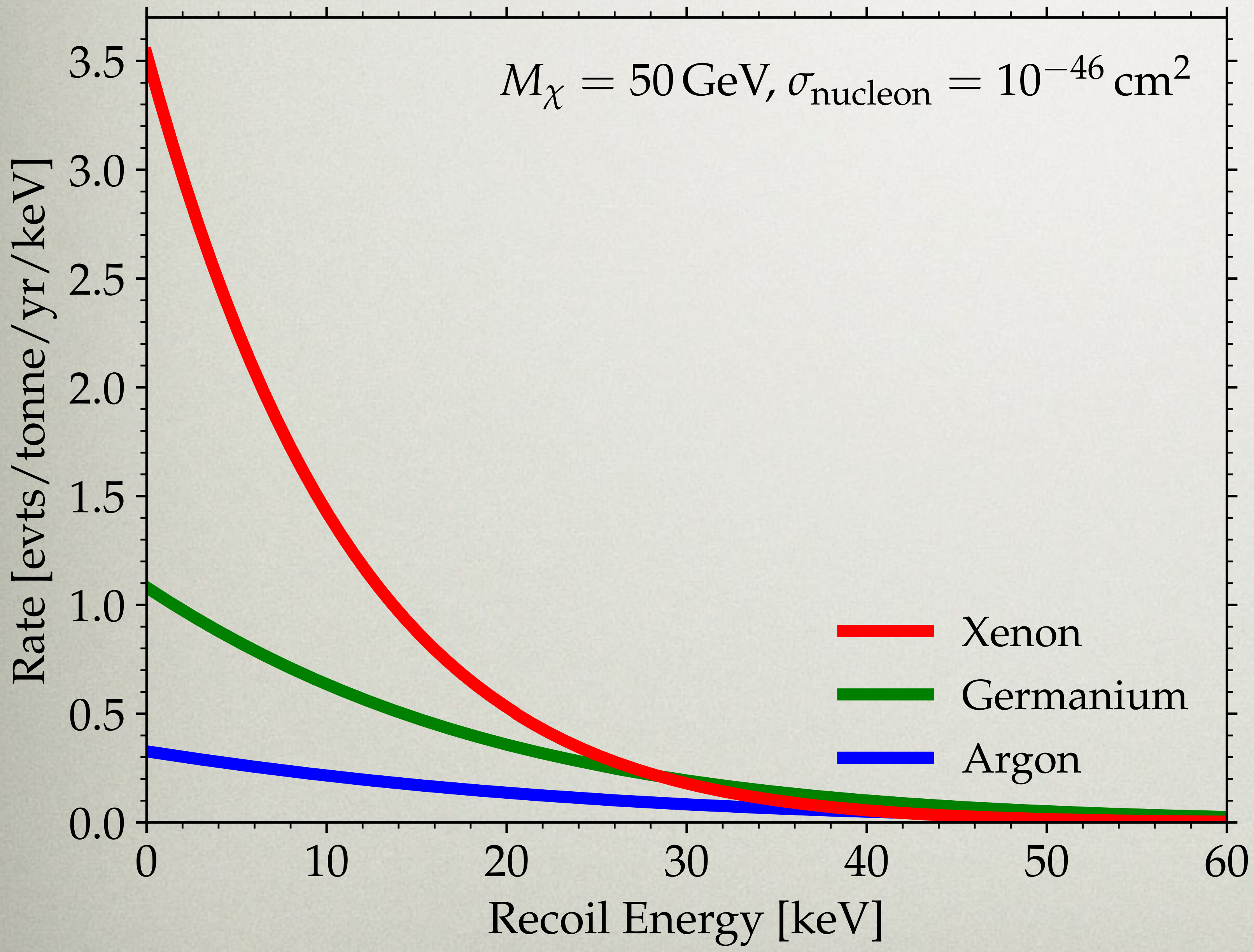


1) IBS Center for Underground Physics (South Korea)
2) LIP Coimbra (Portugal)
3) MEPhI (Russia)
4) Imperial College London (UK)
5) STFC Rutherford Appleton Lab (UK)
6) University College London (UK)
7) University of Bristol (UK)
8) University of Edinburgh (UK)
9) University of Liverpool (UK)
10) University of Oxford (UK)
11) University of Sheffield (UK)
12) Black Hill State University (US)
13) Brookhaven National Lab (US)
14) Brown University (US)
15) Fermi National Accelerator Lab (US)
16) Lawrence Berkeley National Lab (US)
17) Lawrence Livermore National Lab (US)
18) Northwestern University (US)
19) Pennsylvania State University (US)
20) SLAC National Accelerator Lab (US)
21) South Dakota School of Mines and Technology (US)
22) South Dakota Science and Technology Authority (US)
23) Texas A&M University (US)
24) University at Albany (US)
25) University of Alabama (US)
26) University of California, Berkeley (US)
27) University of California, Davis (US)
28) University of California, Santa Barbara (US)
29) University of Maryland (US)
30) University of Massachusetts (US)
31) University of Michigan (US)
32) University of Rochester (US)
33) University of South Dakota (US)
34) University of Wisconsin - Madison (US)
35) Washington University in St. Louis (US)
36) Yale University (US)

Why use liquid xenon?

Why use liquid xenon?

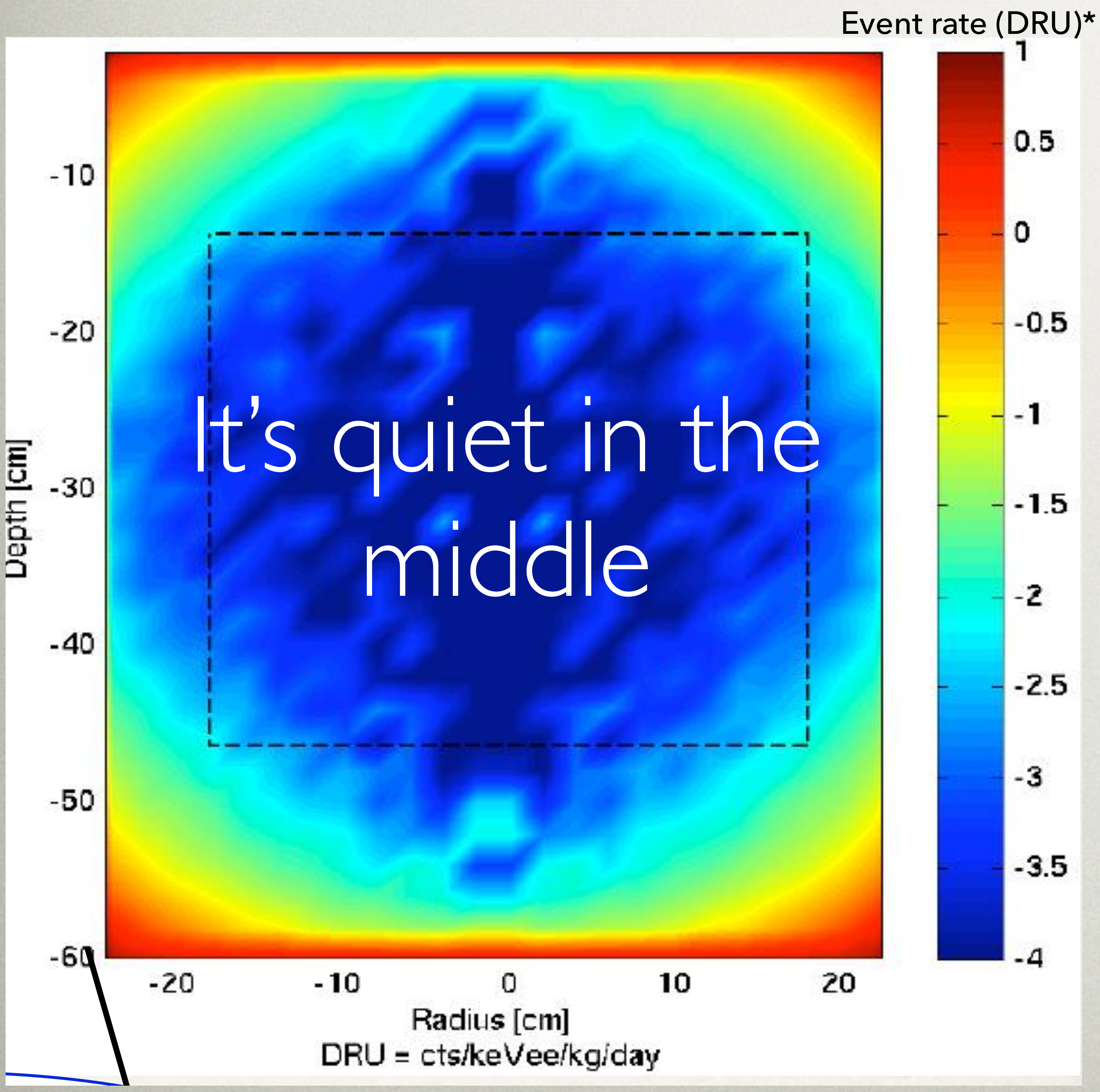
Large signal



- Scalar WIMP-nucleus interactions feature an A^2 dependence on the scattering rate. *Xe has a large A*.
- Natural xenon contains ~50% odd isotopes, giving high sensitivity to spin-coupled interactions

Why use liquid xenon?

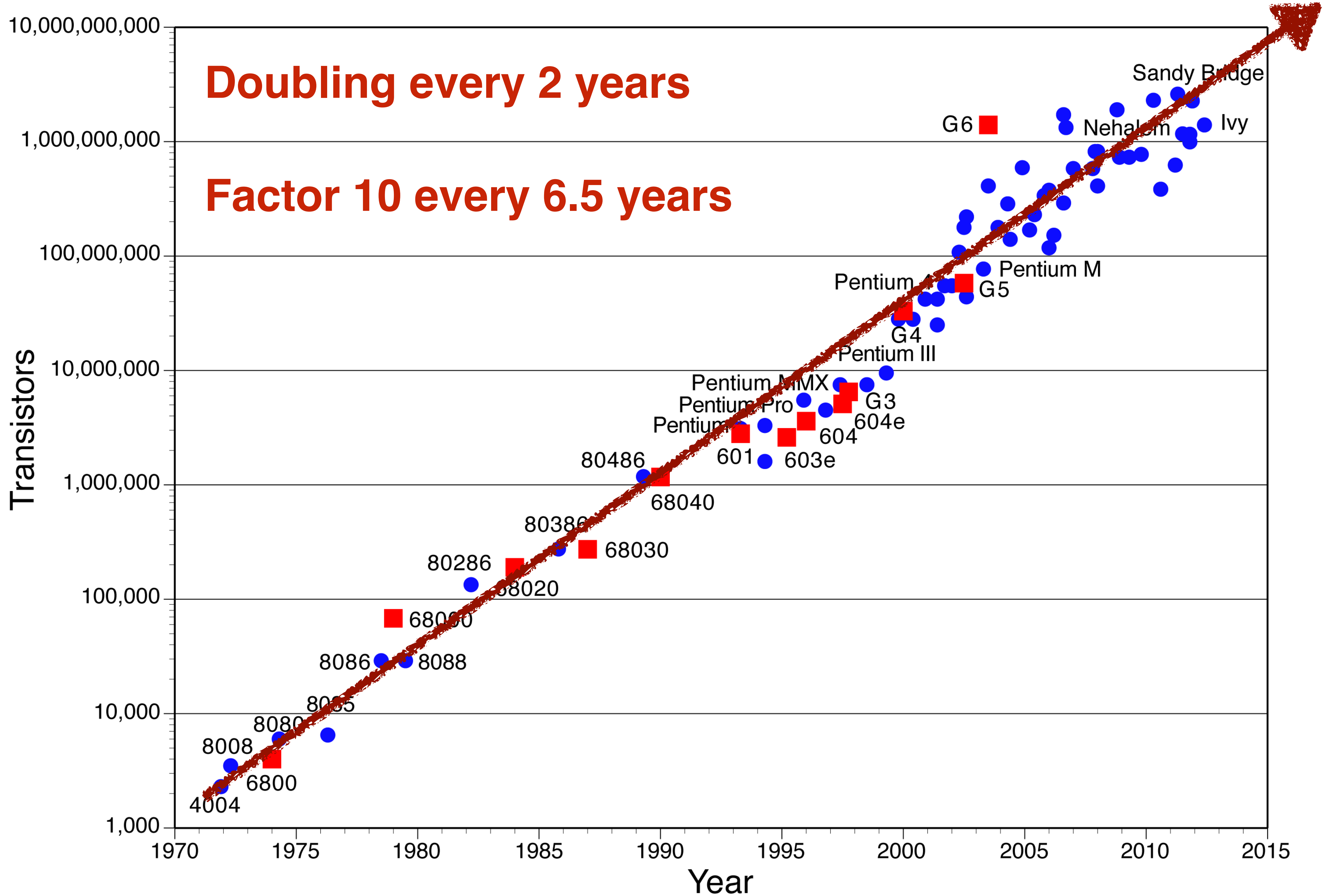
Low background



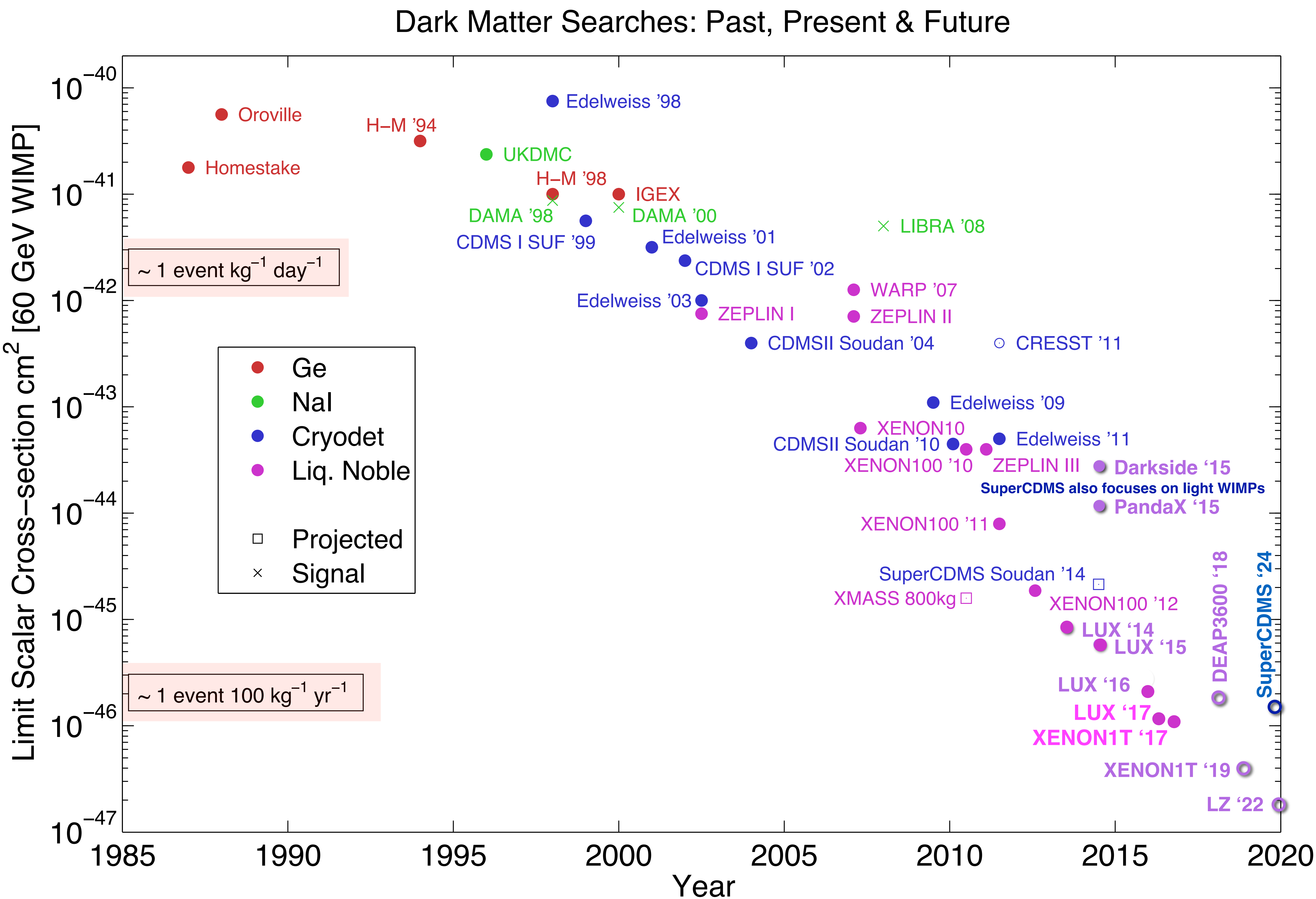
1. Easily scalable to large size
2. 3-D localization of events
3. 1 and 2 permit an ultra-low-background inner region to be defined.

* "DRU" = evt/kg/day/keV

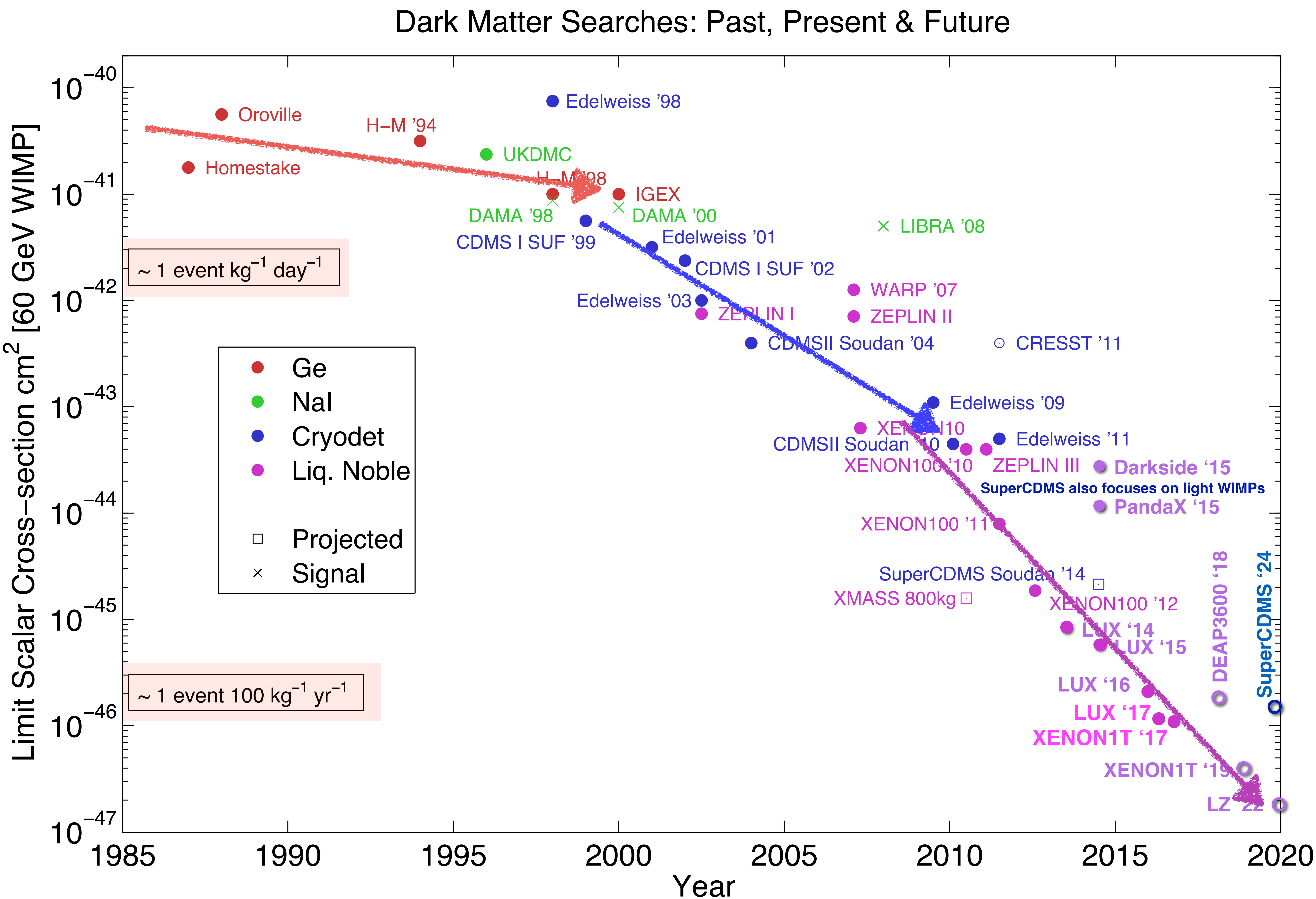
Moore's Law



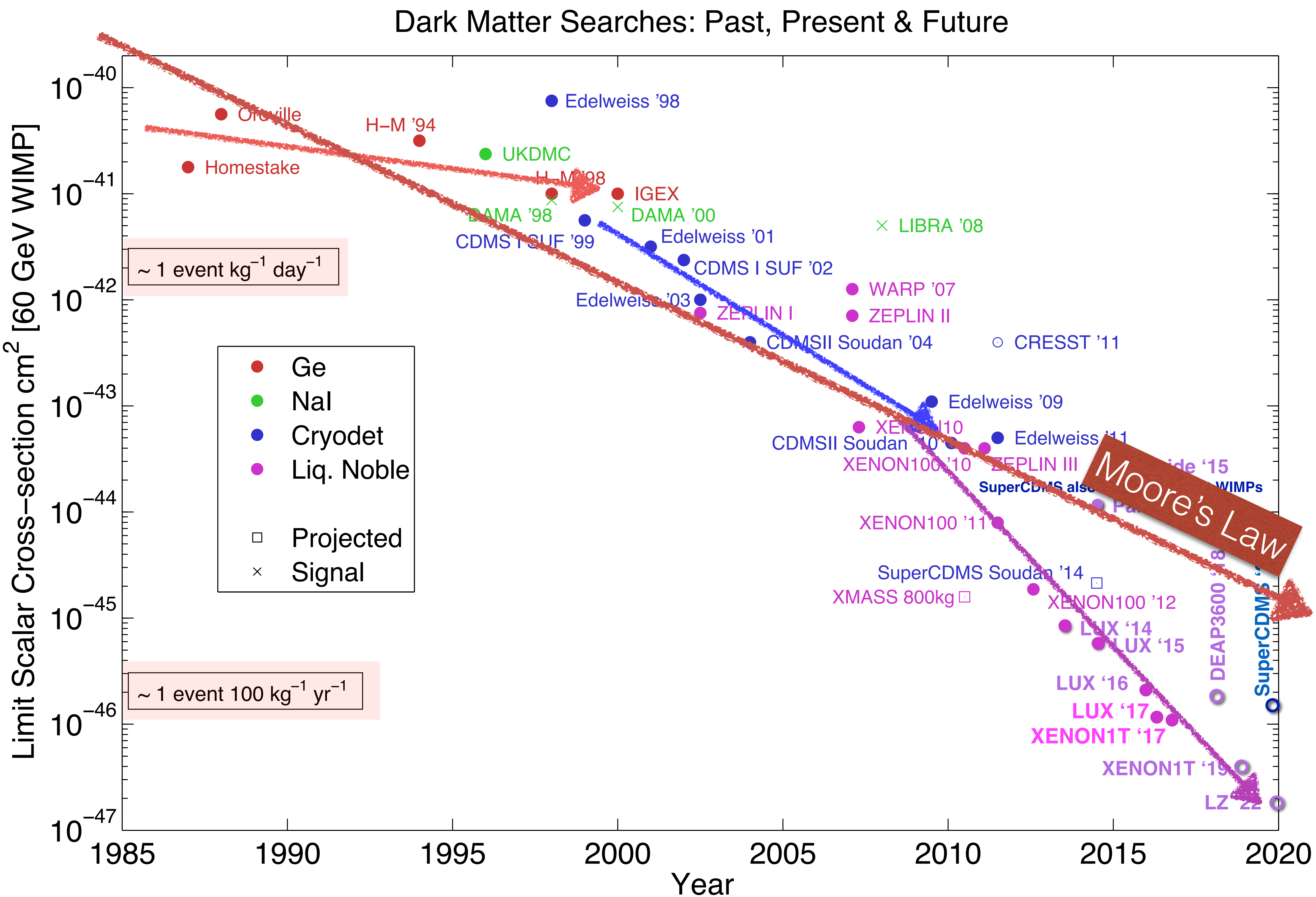
Doubling every 2 years
Factor 10 every 6.5 years
10,000,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
Transistors
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
4004
8008
6800
8086
8088
80286
68030
80486
68040
601
603e
604
604e
G3
Pentium III
G4
G5
Pentium M
G6
Ivy



Courtesy R. Gaitskell



Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section cm2 [60 GeV WIMP]
Year
1985
1990
1995
2000
2005
2010
2015
2020
Oroville
Homestake
H–M '94
Edelweiss '98
UKDMC
H–M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
LIBRA '08
CDMS I SUF '02
Edelweiss '03
ZEPLIN I
WARP '07
ZEPLIN II
CDMSII Soudan '04
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
Darkside '15
SuperCDMS also focuses on light WIMPs
PandaX '15
XENON100 '11
SuperCDMS Soudan '14
XMASS 800kg
XENON100 '12
LUX '14
LUX '15
DEAP3600 '18
SuperCDMS '24
LUX '16
LUX '17
XENON1T '17
XENON1T '19
LZ '22
~ 1 event kg−1 day−1
~ 1 event 100 kg−1 yr−1
Ge
NaI
Cryodet
Liq. Noble
Projected
Signal


Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section cm^2 [60 GeV WIMP]
Year
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
1985
1990
1995
2000
2005
2010
2015
2020
~ 1 event kg^{-1} day^{-1}
~ 1 event 100 kg^{-1} yr^{-1}
Ge
NaI
Cryodet
Liq. Noble
Projected
Signal
Homestake
H–M '94
UKDMC
Edelweiss '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
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WARP '07
ZEPLIN II
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XENON100 '11
Moore's Law
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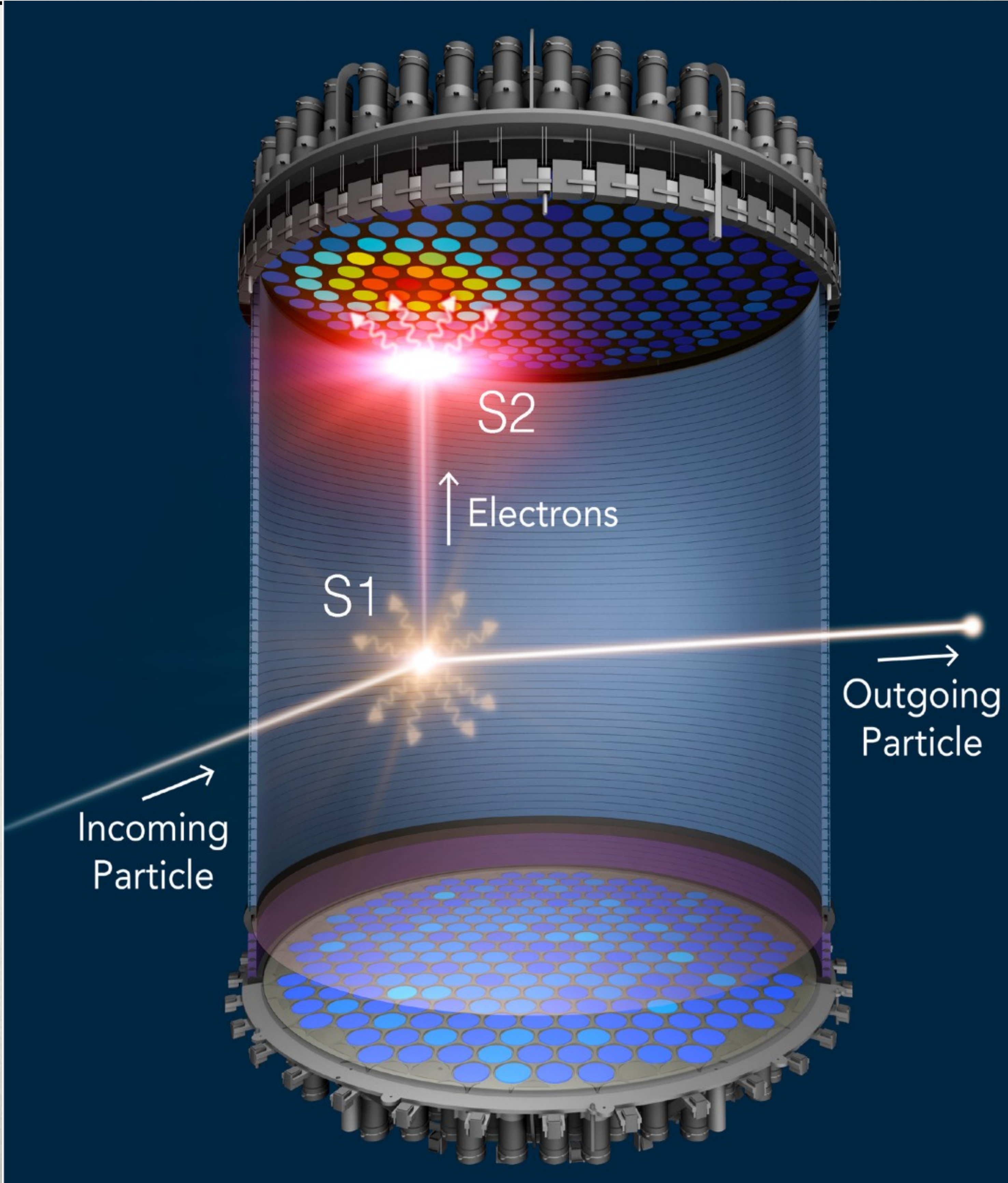
LUX '14
LUX '15
LUX '16
LUX '17
XENON1T '17
DEAP3600 '18
XENON1T '19
LZ '22

Dual-phase time projection chamber (TPC)

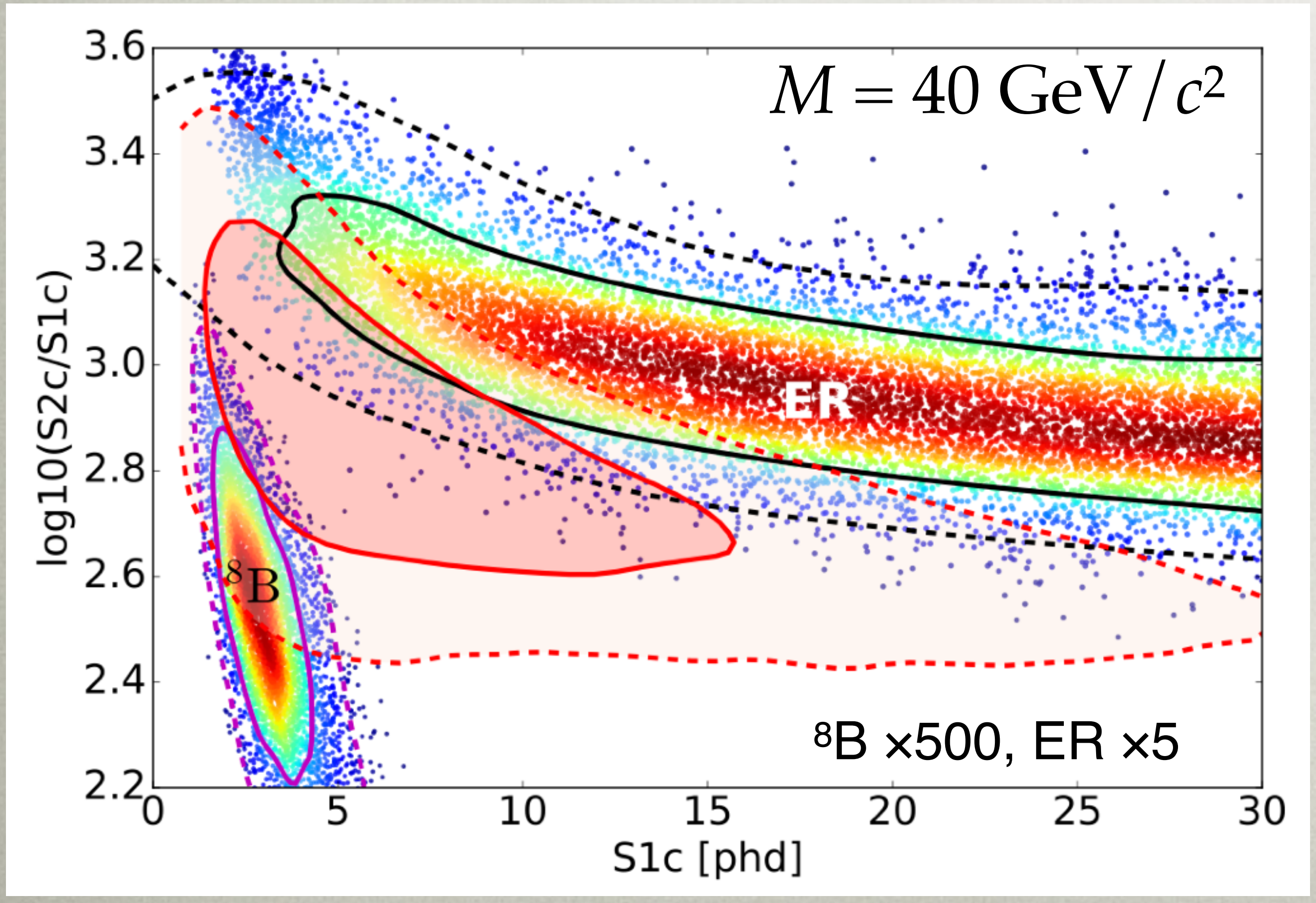
- Main target is liquid xenon (180 K).
- Primary scintillation light (S1) emitted from interaction vertex
- Ionized e⁻ drift to the liq. surface; produce prop. light as they travel through gas (S2).
- S1 and S2 permit:
  - Energy reconstruction
  - 3-D position reconstruction
  - Background rejection

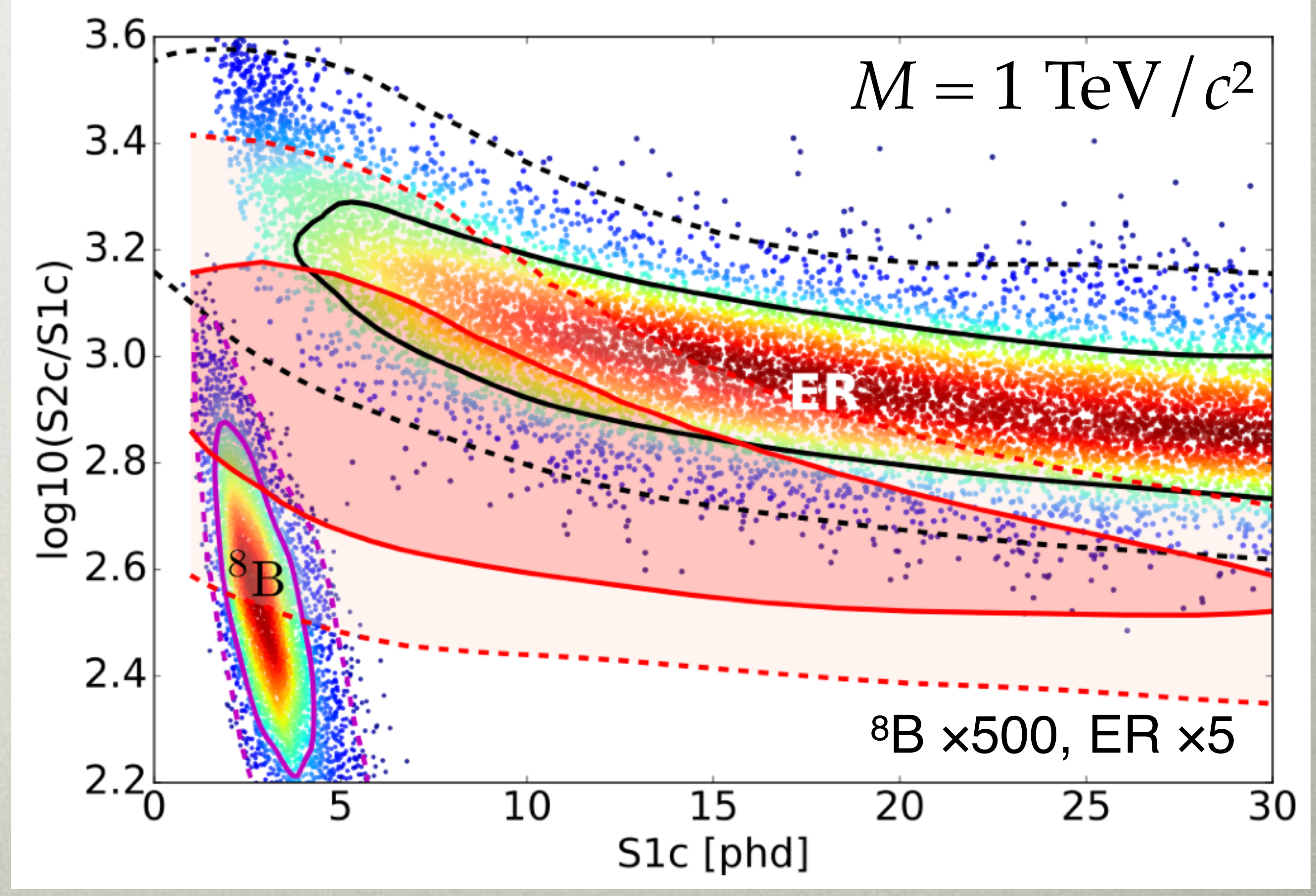
Details in our Technical Design Report: arXiv/1703.09144



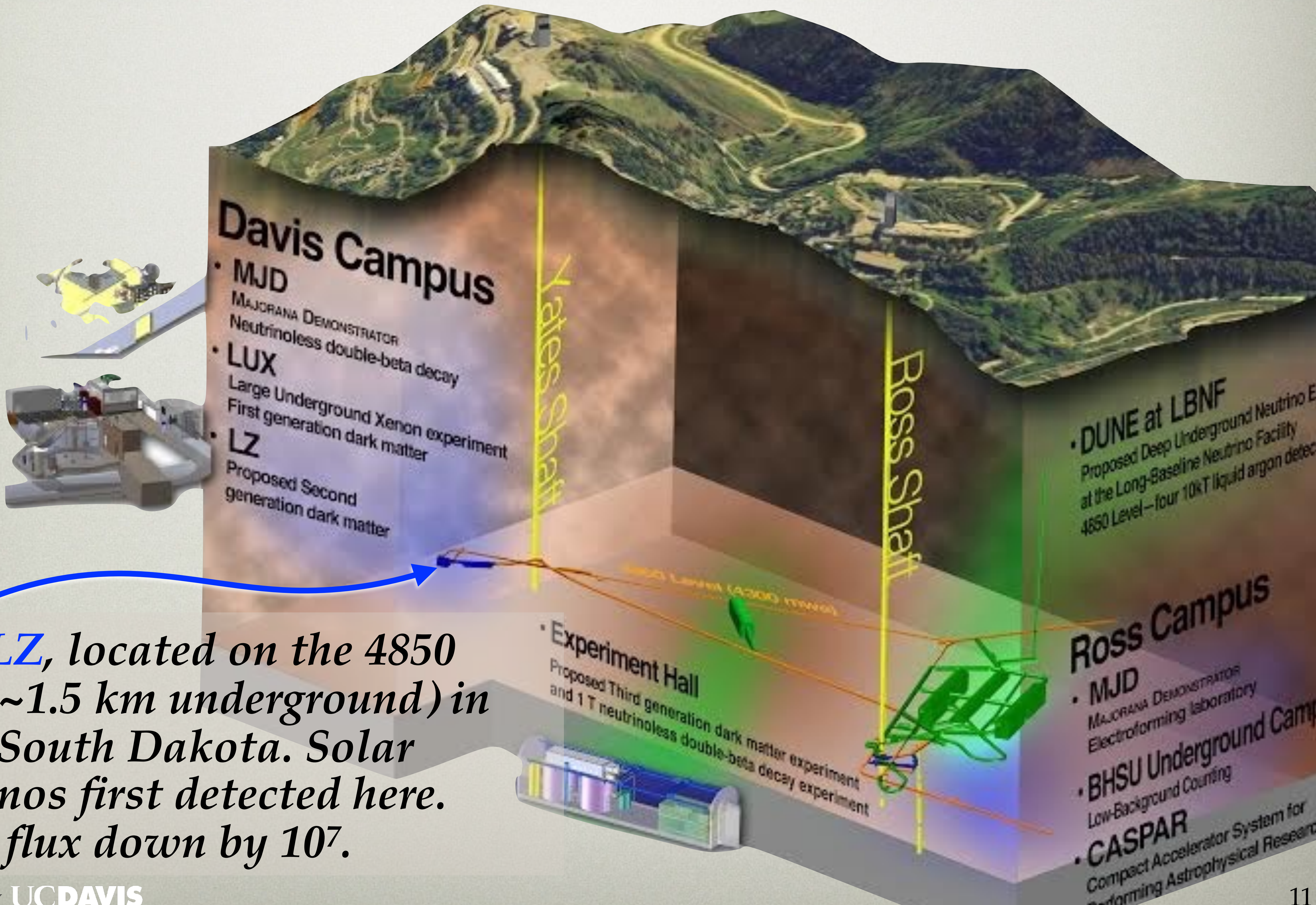
WIMPs: expected signal

- Majority of BG is from electronic recoils (ER).
- WIMPs detected via nuclear recoils (NR).
- ER and NR have different S1 / S2 ratio.
- Shape of observed spectrum gives info on WIMP mass.
- Low mass sensitivity affected by NR from ^{8}B solar neutrinos (~7 events in 1000d, depends strongly on low-en. NR efficiency).





Sanford Underground Research Facility



***LUX/LZ**, located on the 4850 level (~1.5 km underground) in Lead, South Dakota. Solar neutrinos first detected here. Muon flux down by 10^7.*

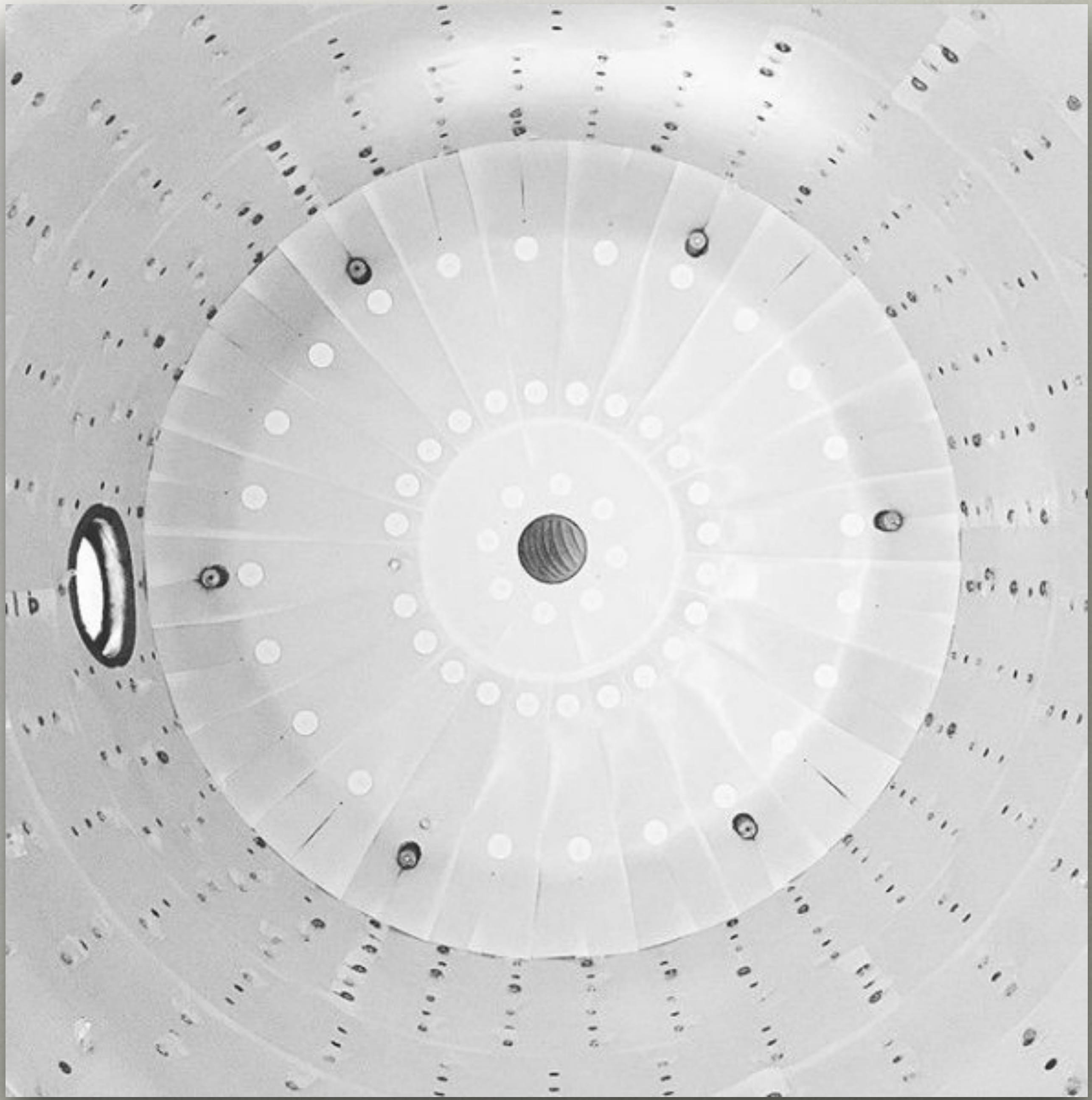
- LZ: factor of ~50 larger fiducial than LUX
- Lower backgrounds

(See talk by Shaw Sally)

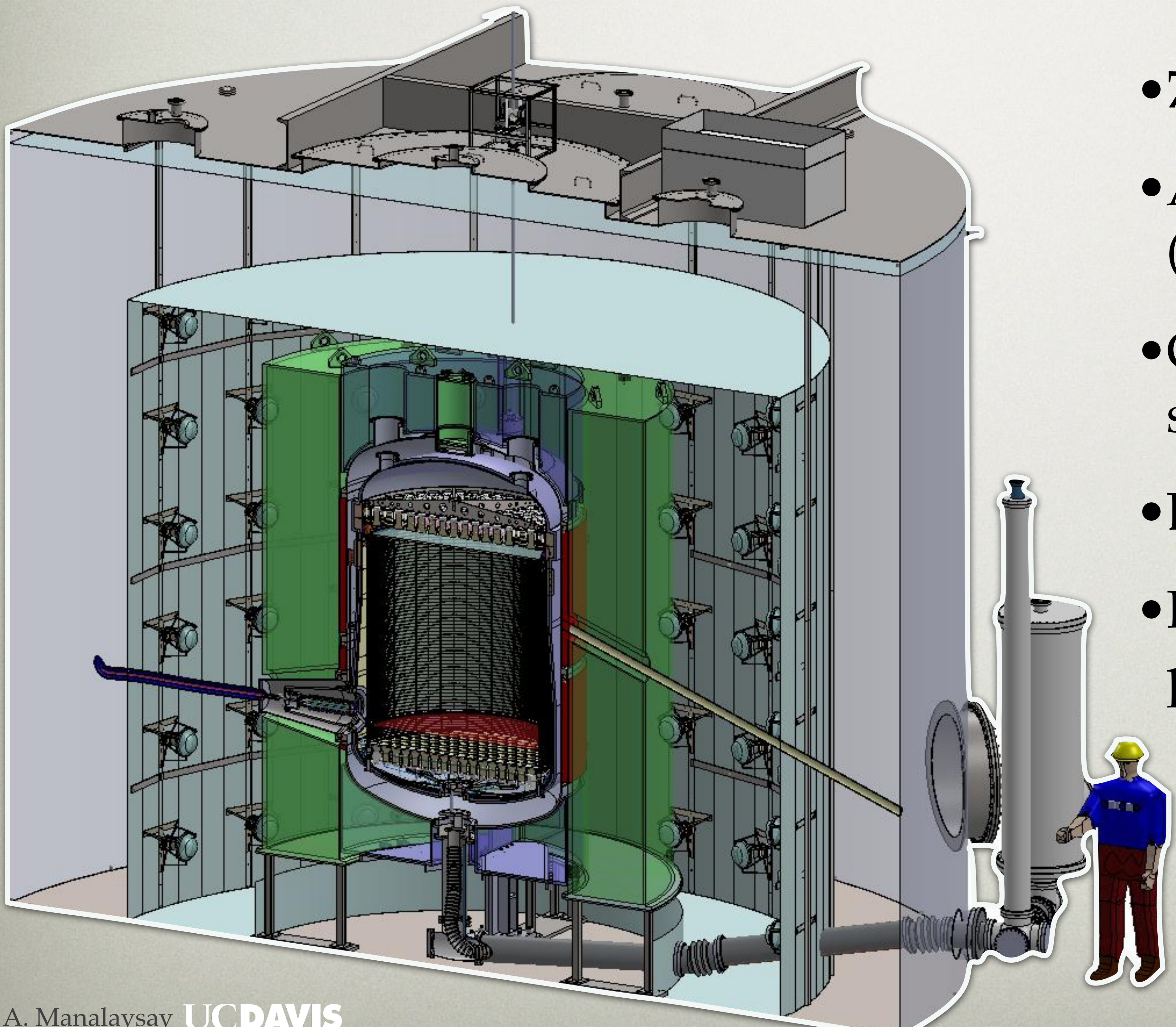
Cryostat vessels

Outer cryostat vessel

UV reflectors in the inner cryostat vessel



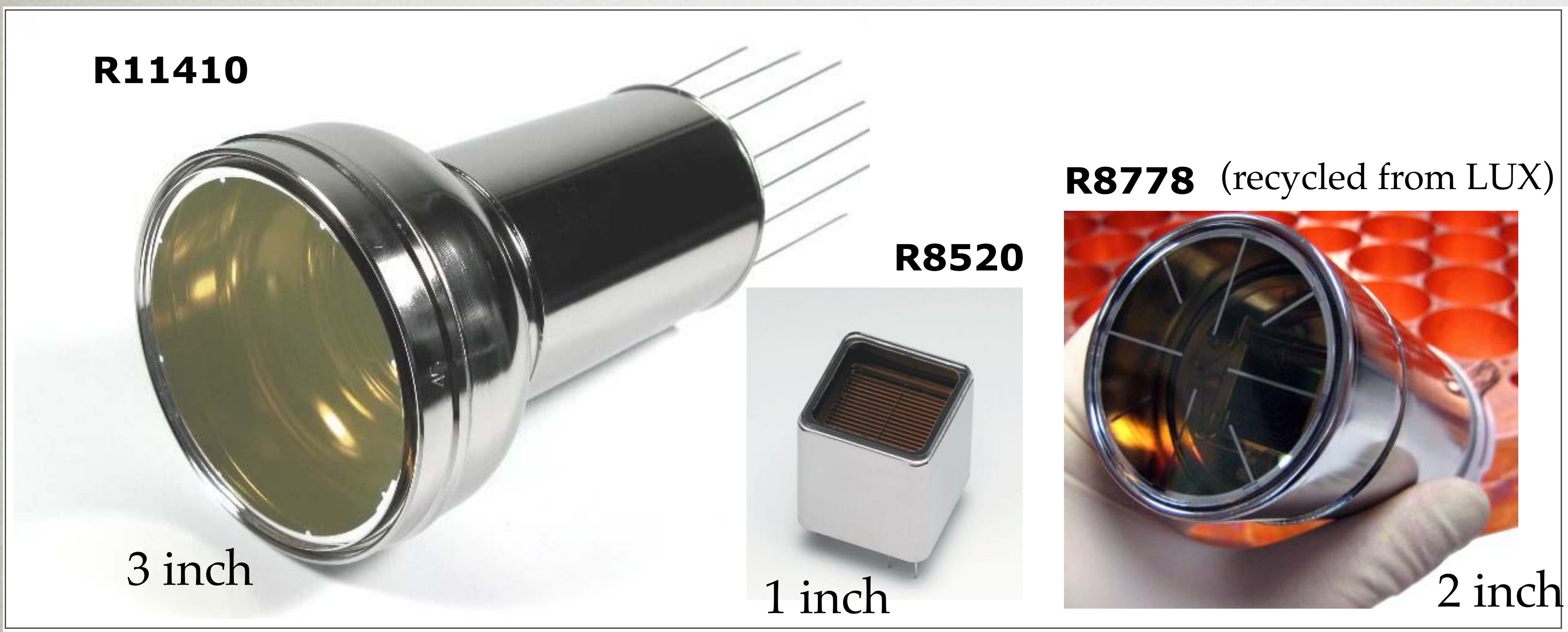
LZ



- 7 tonnes active mass.
- Active LXe "skin" veto (outside of TPC)
- Gd-loaded LAB scintillator veto
- LUX's water shield
- External liquefaction/ purification tower

Photomultiplier Tubes

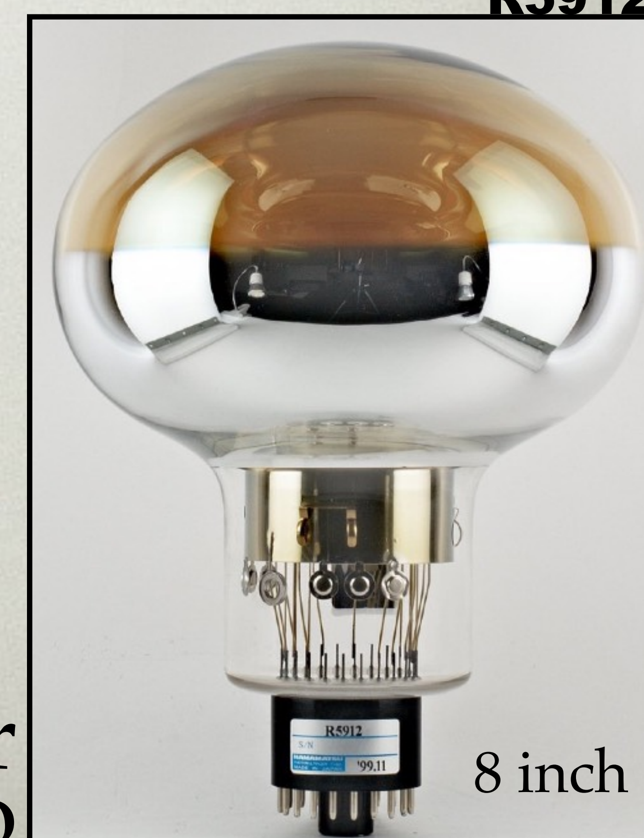
Hamamatsu



Main TPC

Xe “skin” veto

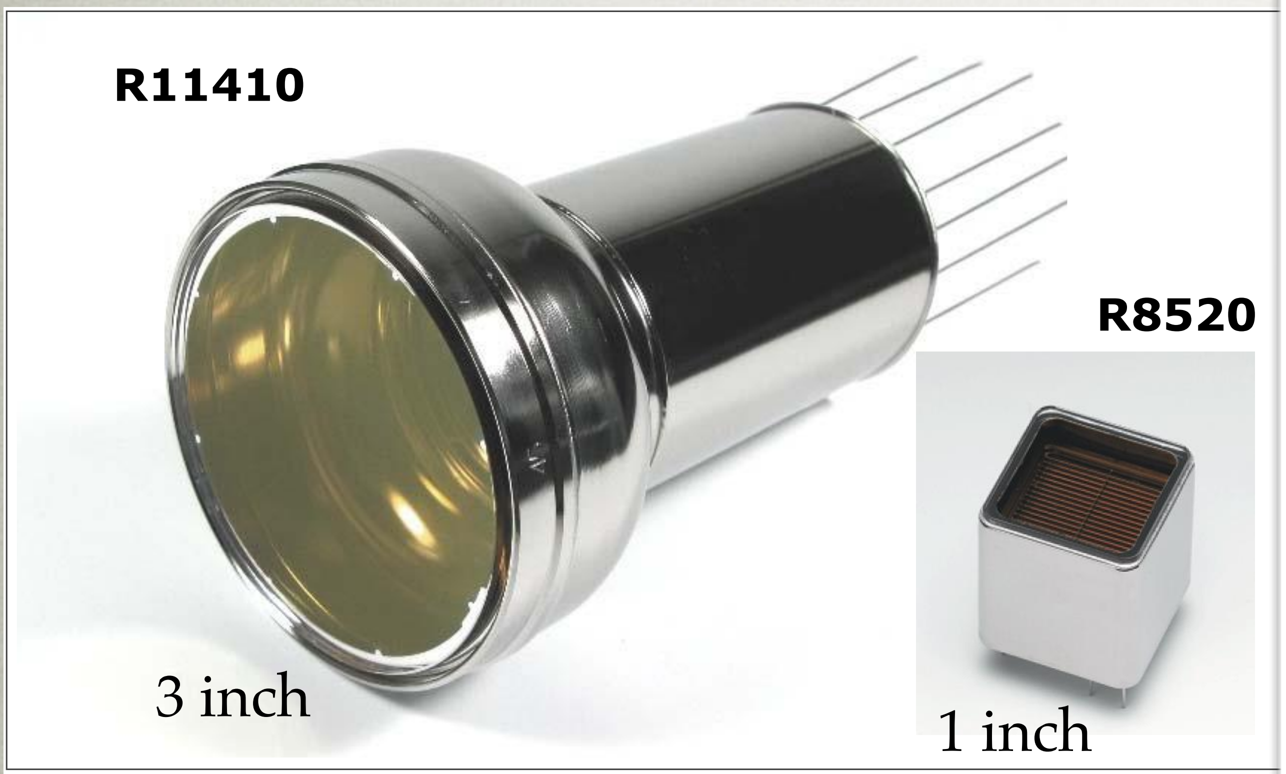
R5912



Scintillator veto

Photomultiplier Tubes

Hamamatsu



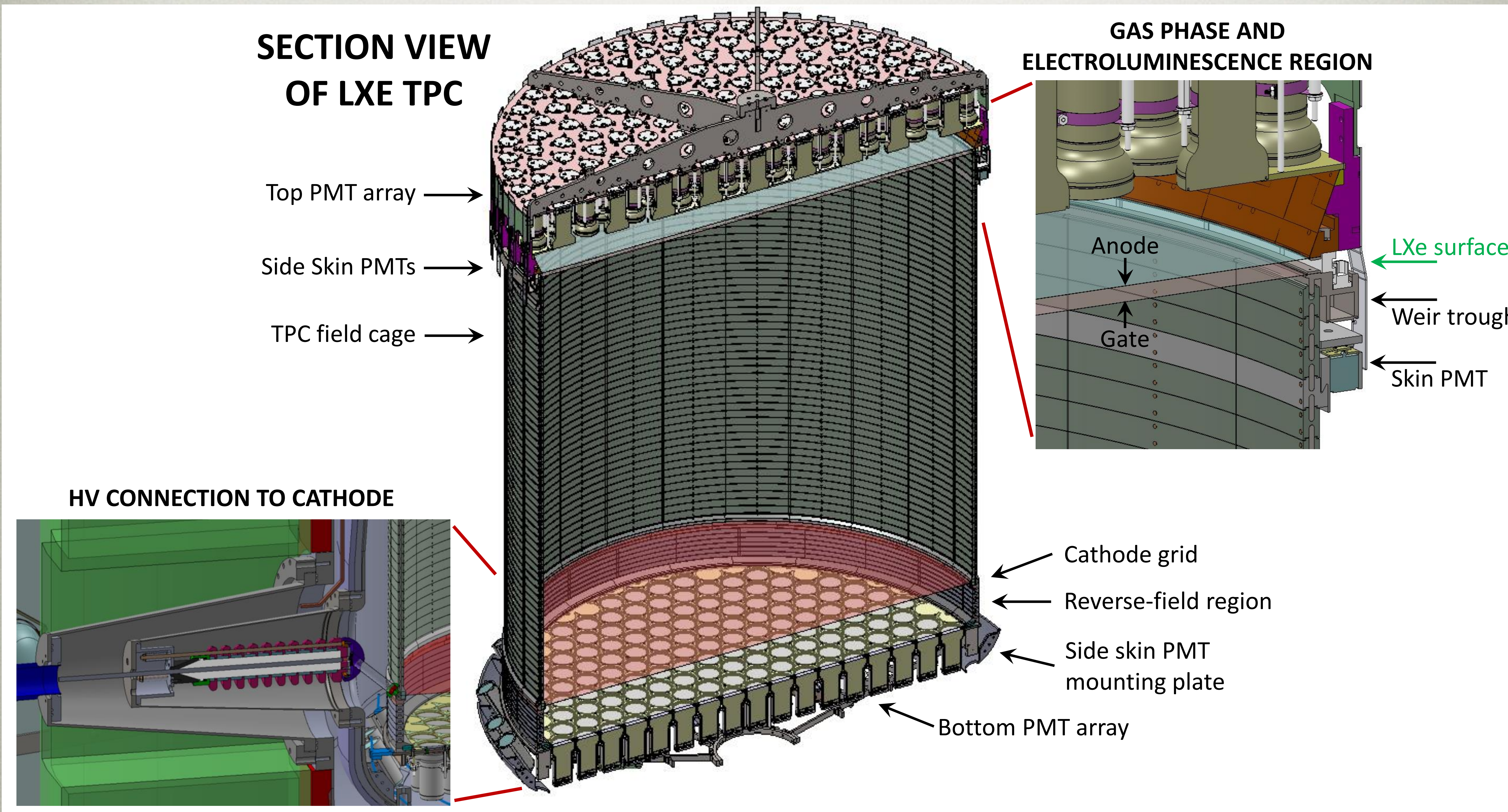
Main TPC

Xe “sk

Completed lower PMT array

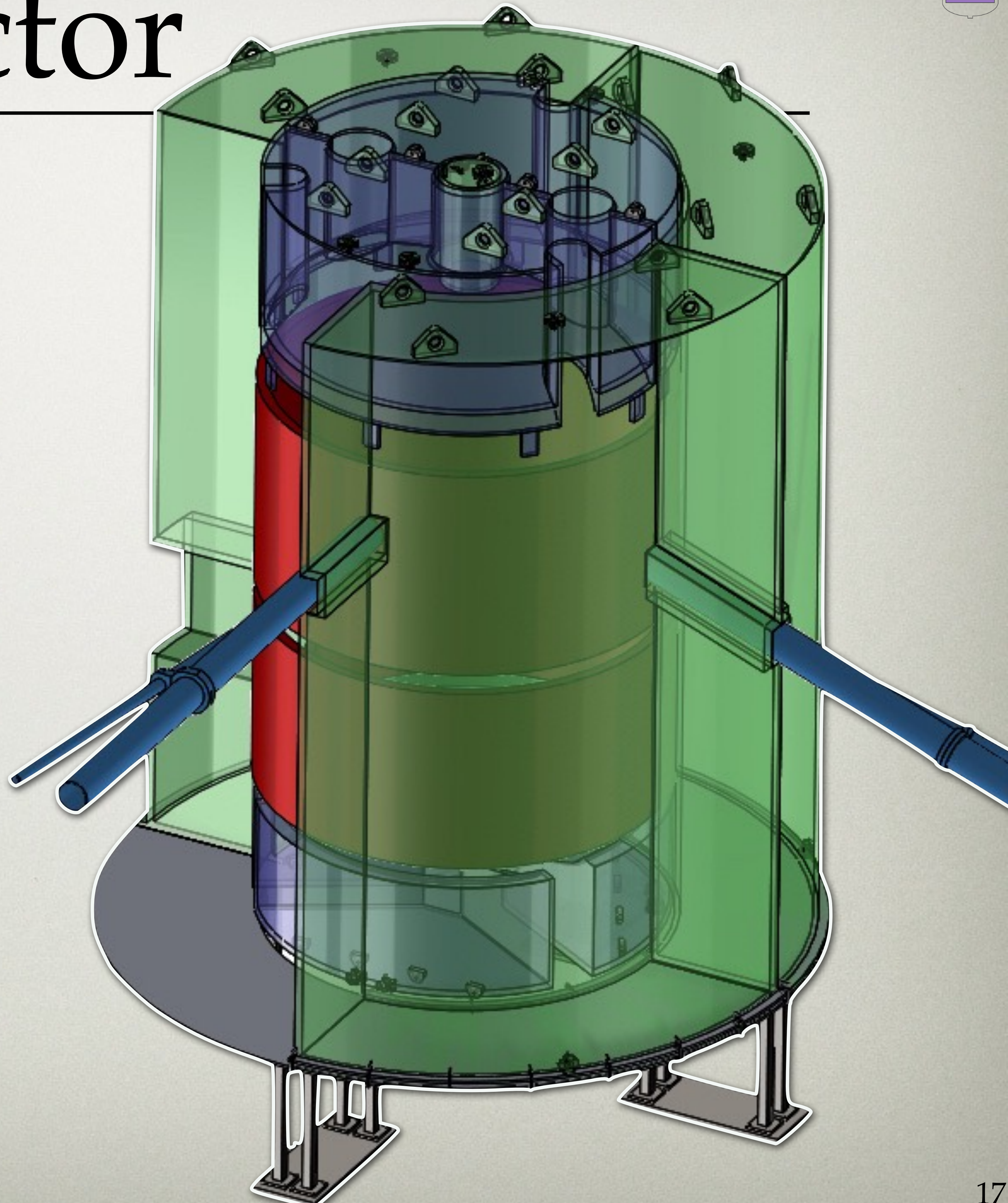
Scintillator veto

TPC

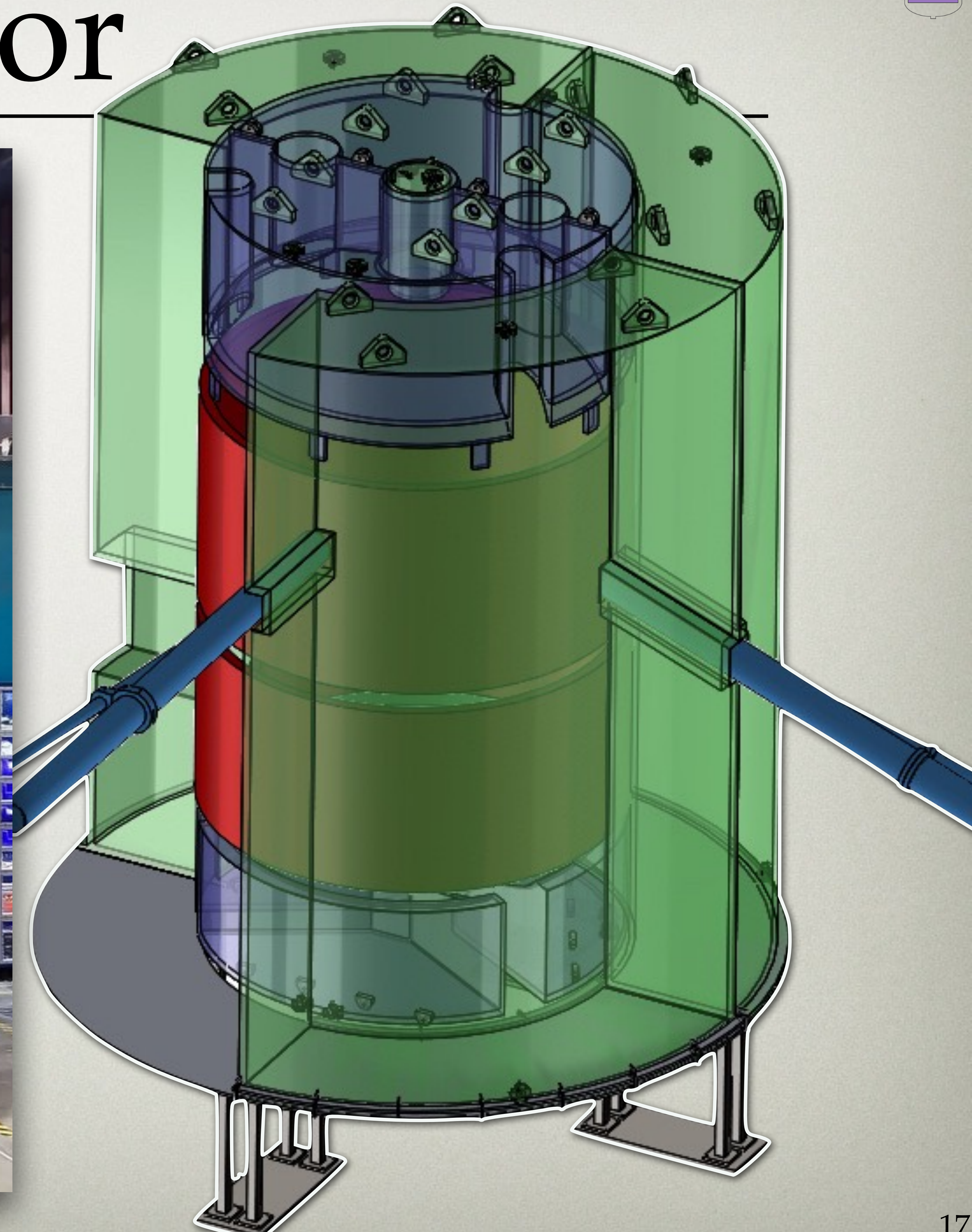

SECTION VIEW
OF LXE TPC
Top PMT array
Side Skin PMTs
TPC field cage
GAS PHASE AND
ELECTROLUMINESCENCE REGION
Anode
Gate
LXe surface
Weir trough
Skin PMT
HV CONNECTION TO CATHODE
Cathode grid
Reverse-field region
Side skin PMT
mounting plate
Bottom PMT array

Outer detector

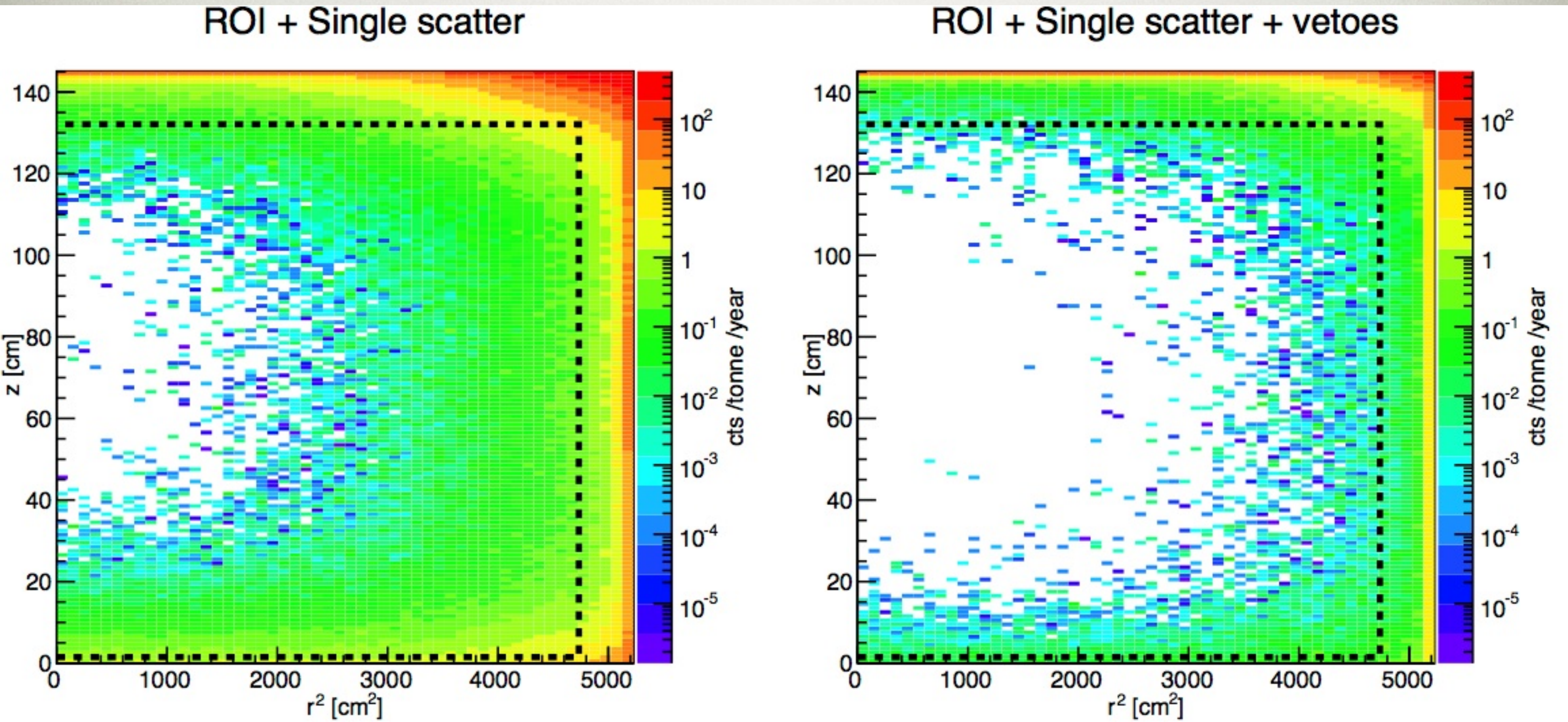
- Gd-doped LAB liquid scintillator.
- Neutron and gamma veto.
- 4π coverage
- Cutouts for cryogenics, electronics, neutron tubes, HV
- Screener vessel already deployed in LUX water shield, good results.



Outer detector



Backgrounds

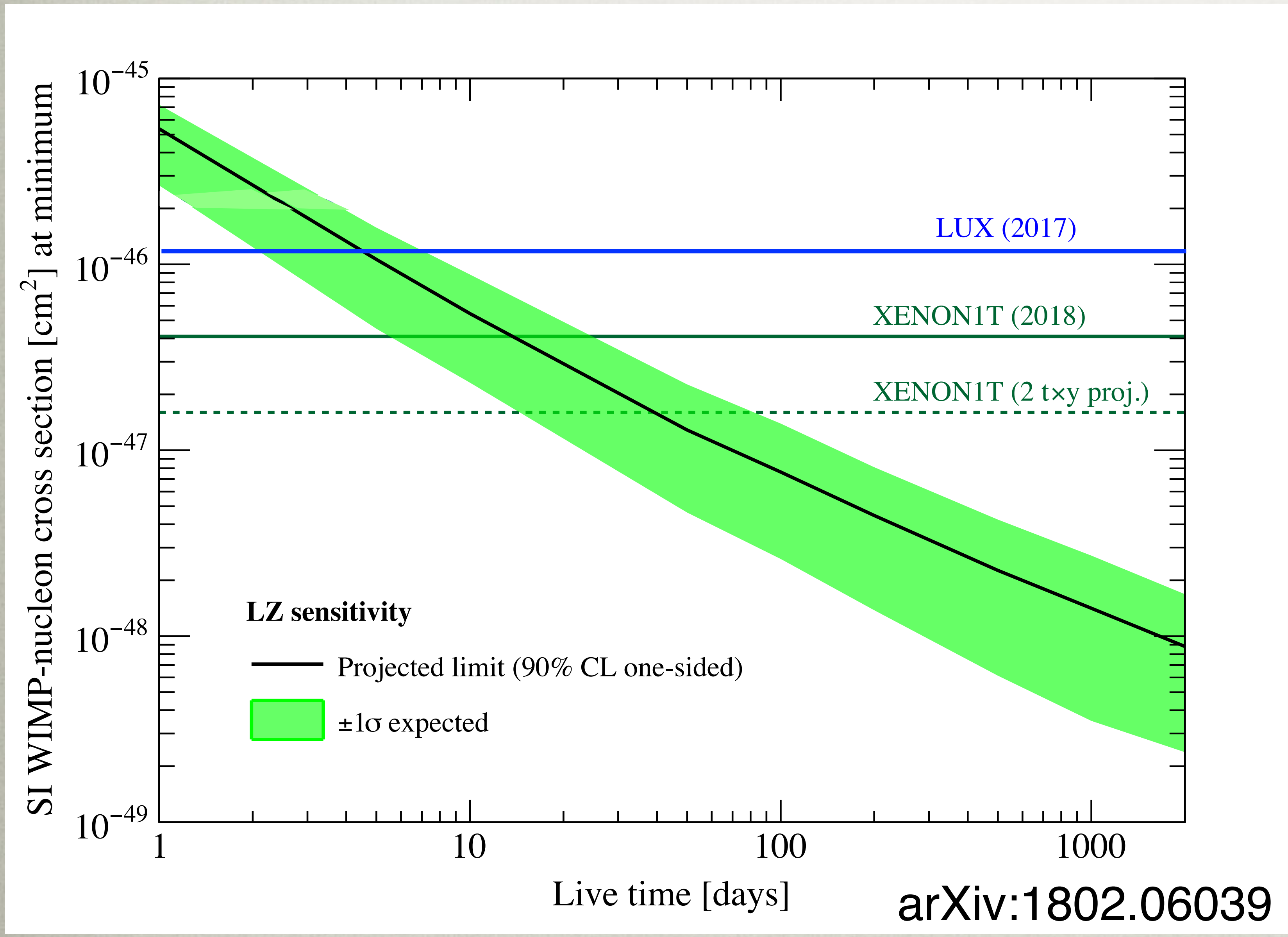


No vetoes

With vetoes (LXe skin and liquid scint.)

Scientific Reach — Standard WIMPs

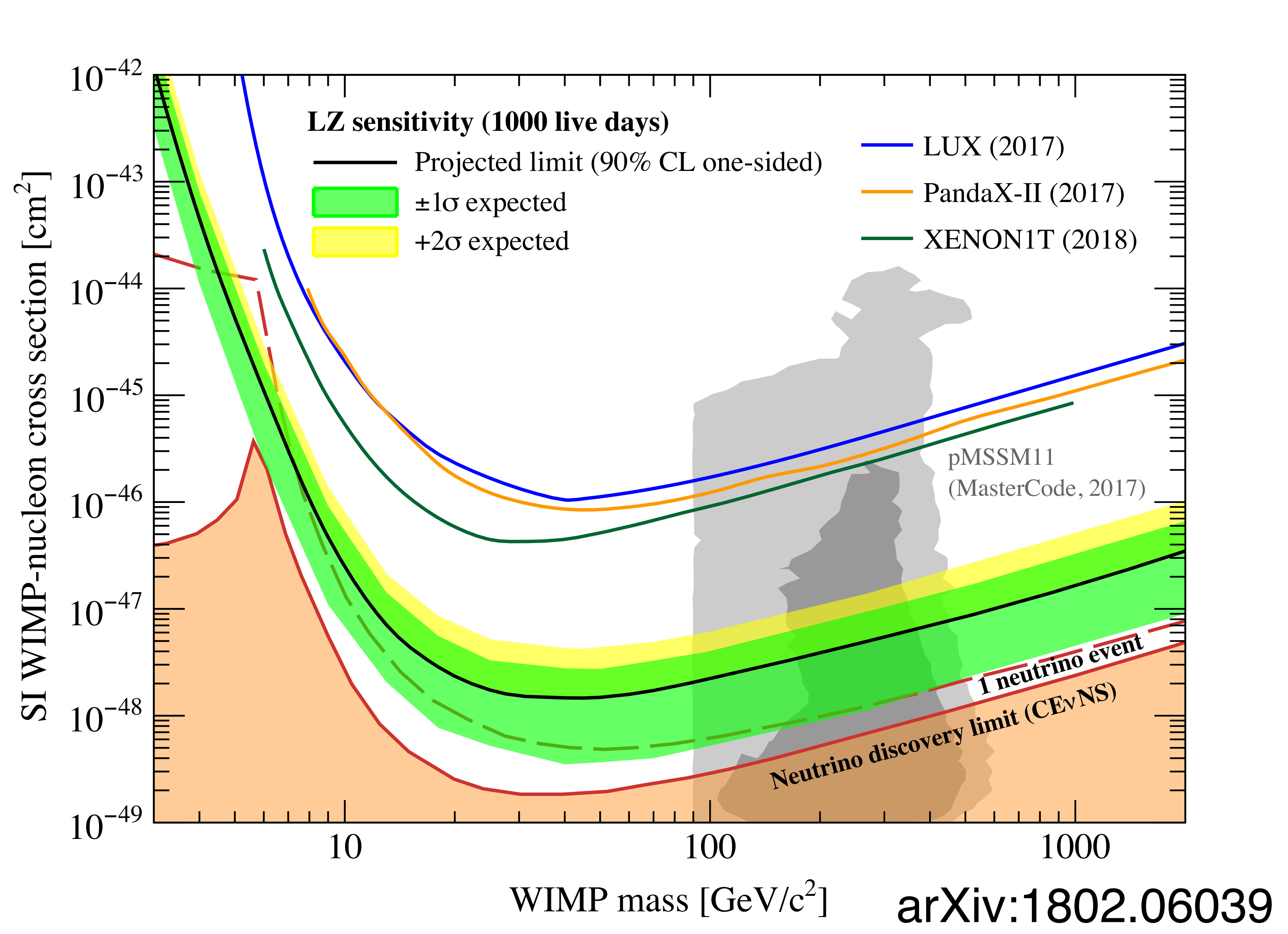
Min. SI sensitivity vs. live-time



- Reach LUX sensitivity within ~4-5 days
- Reach XENON1T (2018) sensitivity within ~2 weeks
- Min. sensitivity 1.6×10^{-48} cm^2 after 1000 live-days

Scientific Reach — Standard WIMPs

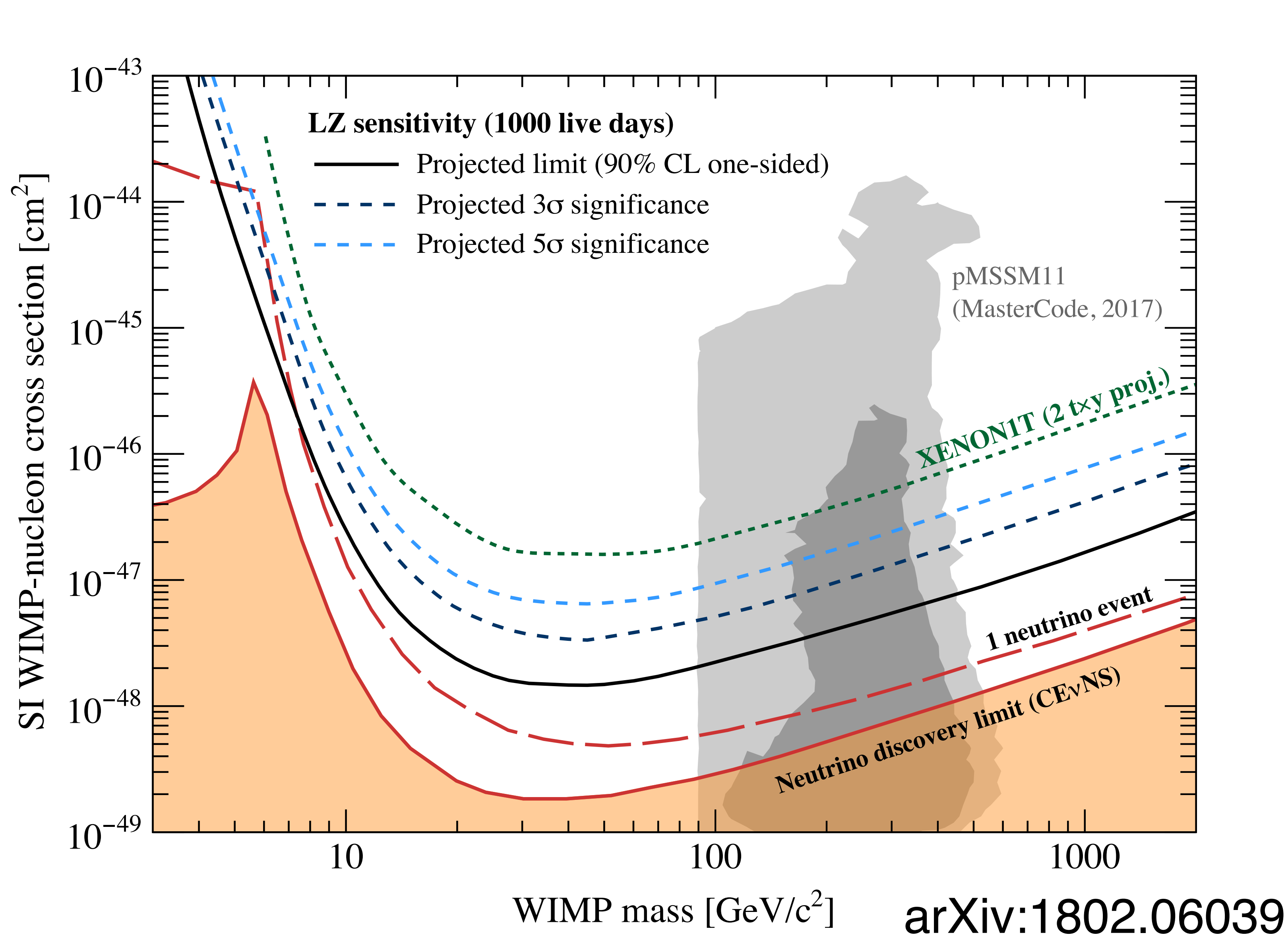
Proj. [SI] sensitivity vs. WIMP mass



- With LZ, we begin to probe a significant region of param. space favored in pMSSM
- Sensitivity not yet limited by CNNS irreducible BG
- But expect to see many CNNS events from ^8B, and potentially 1 event from atm+DSNB.

Scientific Reach — Standard WIMPs

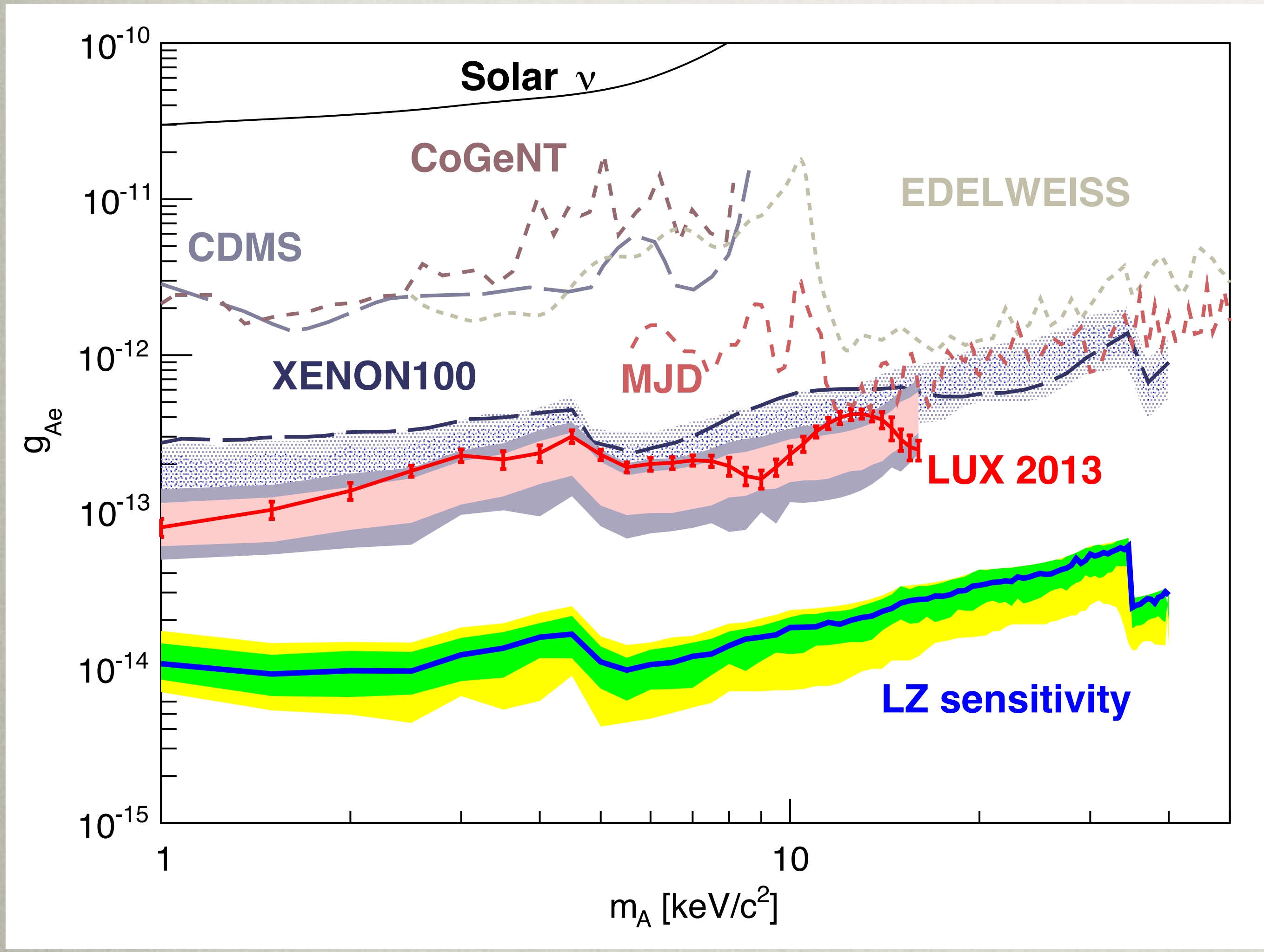
Discovery potential



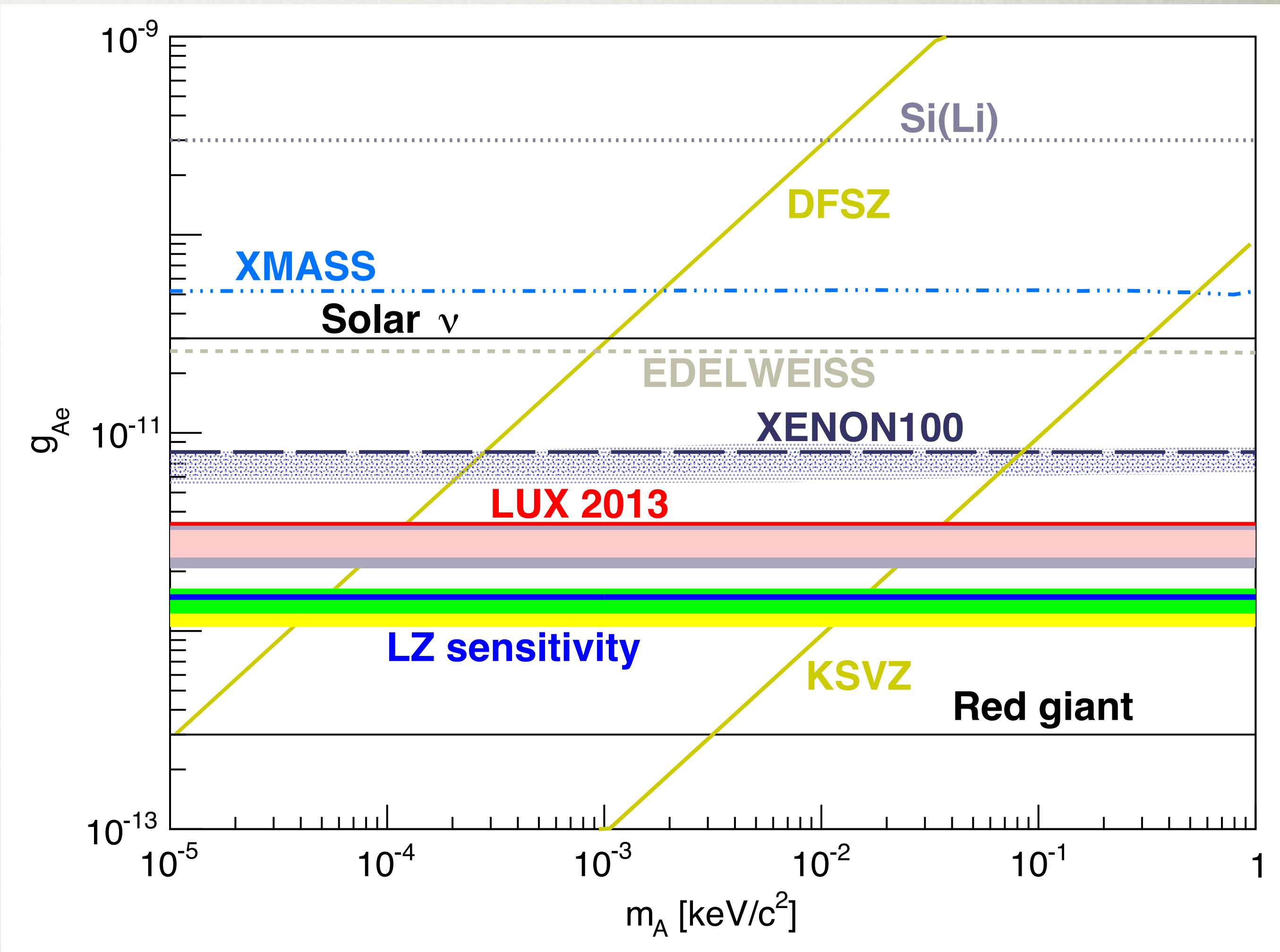
- Setting limits is great, but
- Really we are doing this to make a detection.
- Projected detection potential reaches (at min)
  - 3.8×10^{-48} cm^2 at 3σ
  - 6.7×10^{-48} cm^2 at 5σ

Scientific Reach — Axions and ALPs

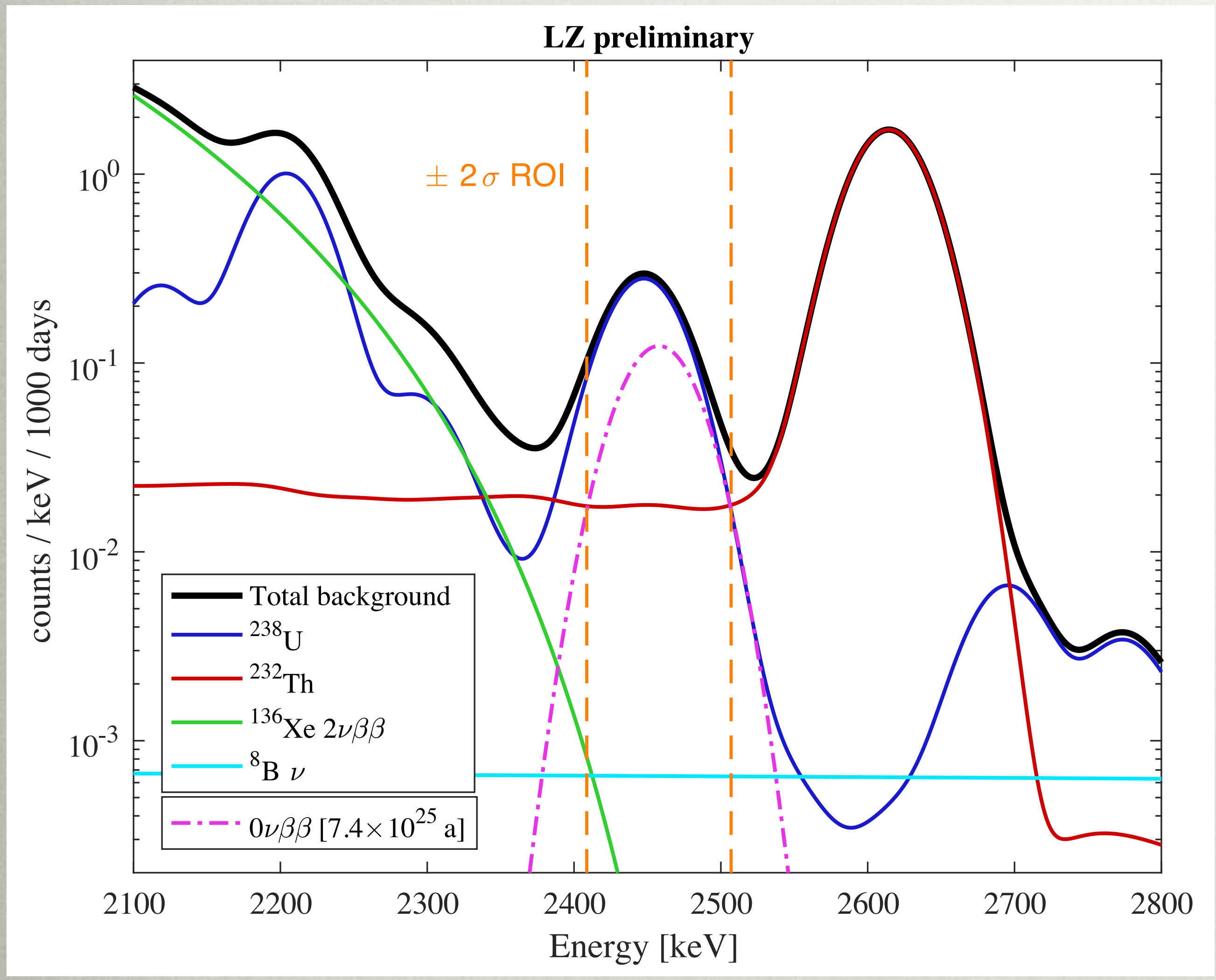
Dark-matter ALPs



Solar axions



Neutrinoless double beta decay



- ^{136}Xe Q value at 2458 keV
- We project 1% energy resolution at Q value.
- Main BG from PMTs+Cryostat
- Dedicated fiducial volume: 957 kg (BG optimized)
- 1000 live-day run
- **Median 90% CL sensitivity on $^{136}Xe\ 0\nu\beta\beta$ half-life:**

$$T_{1/2}^{0\nu} > 0.74\times10^{26} \text{ years (median)}$$

Summary

- Noble-liquid TPCs leading the field in sensitivity to WIMP
- LZ is the successor to ZEPLIN and LUX. 7 tonnes LXe (5.6 tonnes fiducial)
- LZ will reach sensitivity of 1.6×10^{-48} cm^2 for SI WIMP-nucleon interactions. Other dark-matter results expected as well.
- Sensitivity to $0\nu\beta\beta$ of ^{136}Xe of 0.74×10^{26} years
- LZ is at an advanced stage. Construction already begun, planning first science data in 2020.